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Designing a Low-Carbon Building via LCB Method 3.0, Case Study: An Educational Building in Tehran

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Abstract: Air pollution and its damage have caused growth of concerns in human societies in the last decades. Nowadays, environmental issues are being discussed more than ever and sometimes it leads to solutions and methods to improve current situations. One of the methods is introduced in 2009 as Low-Carbon Building (LCB) Method. This method considers reduction of emissions in building during its whole lifetime. In this study, an educational building is designed with the purpose of considerable reduction in greenhouse gas (GHG) emissions. This building is investigated in different stages and eventually, the amount of carbon emissions in the building's lifetime is estimated by LCB Method 3.0 which is built on Publicly Available Specification (PAS) 2050. After estimation, it is determined that the project building, according to low-carbon buildings classification, can be ranked in Class C (good). This study also discusses effective strategies which lead to low-carbon buildings.

Keywords: GHG emissions, Low-Carbon Building (LCB) Method, LCB Method 3.0, PAS 2050, Low-carbon buildings

INTRODUCTION

Human society and the environment interact with each other. Human impacts on the environment refer to the impacts of human activities on biophysical environments, biodiversity and other resources (Han, 2012). Those activities (such as burning fossil fuels and deforestation) are responsible for the release of considerable amount of greenhouse gas (GHG) in the atmosphere which has the property of trapping solar heat. Climate model projections indicate that global surface temperature will likely rise 1.1°C to 6.4°C during the 21st century. This elevation in temperature causes "changes" to the average weather of regions or the earth as a whole "climate change" (Fabre, 2009). The built environment is one clear example of GHG emissions, so buildings produce considerable impact on the environment (United Nations Environment Programme, 2009). For instance, in the Tehran region, due to the very high energy consumption, carbon dioxide (CO_2) emissions are also very high, with the residential and commercial buildings making up the largest share of 41% by 2008 (Nasrollahi, 2013). Therefore, the idea of low-carbon buildings could be a solution to reduce the excessive GHG emissions in Tehran.

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Low-carbon building is a building which has been engineered to release significantly less GHG than a regular building over its lifetime (Ambapkar, 2015). Life Cycle Assessment (LCA) tools are needed in order to calculate GHG emissions from buildings. Between available tools, Low-Carbon Building (LCB) Method is used in this study. Further, this study introduces the concept of "low-carbon" buildings and LCB Method. Therefore, this paper is focused on following issues:

1. Estimating buildings lifetime GHG emissions and emissions reduction performance.
2. Low-carbon buildings design strategies and criteria which should be employed to reduce GHG emissions.

These issues are discussed and investigated with a case study and estimations are based on a LCB Method 3.0 (third edition).

LIFE CYCLE ASSESSMENT (LCA)

LCA is a technique to assess environmental impacts associated with all stages of a product's life (from raw material extraction through material processing, manufacture, distribution, use, repair and maintenance, disposal or recycling) (Sanders and Wood, 2014). In recent years, LCA software tools have become increasingly important. Today a large number of LCA programs are available. The foremost – and for the potential user also often prohibitive – property of a software tool is the price. The price of an LCA software tool can vary between several thousand euros and free of charge. Some tools offer a wider range of features than others. Some are focused on a specific field of LCA, e.g. LCA in waste management (Unger, Beigl and Wassermann, 2004).

Different groups of LCA software users can be distinguished. The first group includes scientists and researchers. The users in this group make high demands on LCA software tools: they need a flexible software tool that enables them to model "common" often-modelled scenarios as well as scenarios that diverge from the standard. Also the tool should support modelling of complex process chains. Industry, on the other hand, uses LCA software to improve its environmental performance, for process optimisation and product development. The users want "ready to-use" software, where many of the specifications are already pre-set with only a few parameters needing to be determined. Also decision makers use LCA to compare different solution options and hence also LCA software tools. Decision makers generally want an easy-to-understand presentation of the results in terms of which option is the best (Unger, Beigl and Wassermann, 2004).

This study is focused on a building industry. Table 1 includes some of existing building industry LCA tools.

Table 1. LCA Tools in Building Industry

Tool Name	**Supports Full LCA**	**LCA Scope Addressed, A–D***	**Free?**	**Description**
Athena EcoCalculator	No	A, B, C	Yes	This tool is useful for a quick analysis to compare the life cycle impacts of primary elements of building construction.
Athena Impact Estimator	No	A, B, C	Yes	The Athena Impact Estimator is a detailed tool for evaluating multiple or individual material assemblies.
BEES	Yes	A, B, C, D	Yes	The BEES software brings to your fingertips a powerful technique for selecting cost-effective, environmentally-preferable building products.
Boustead Model	Yes	A, B, C, D	No	The Boustead Model is a self-contained database and software application, which enables the user to construct full lifecycle inventories for virtually any process situated anywhere in the world.
Build Carbon Neutral	No	A	Yes	The Build Carbon Neutral Calculator is a simple to use, online calculator that requires the user to input data into only nine fields.
Eco-Bat	N/A	N/A	No	Eco-Bat offers the possibility to quickly perform the life cycle impacts analysis of a building. This tool is specially designed to be used during the conception phase.
Envest 2	No	A, B, C	No	Envest 2 is an online tool that allows the user to model the environmental and whole life costing impacts through the construction and operation of a whole building over a specified time period.
Green Footstep	No	A, B	Yes	Green Footstep accounts for carbon emissions three ways: Site development, construction, and building operations.
Integrated Environmental Solution (IES)	Yes	A, B, C, D	No	Integrated Material Profile And Costing Tool (IMPACT) allows construction professionals to measure the embodied environmental impact and life cycle cost performance of buildings. IMPACT is being developed by a consortium led by BRe Global and IES.

(continued on next page)

Table 1. (*continued*)

Tool Name	**Supports Full LCA**	**LCA Scope Addressed, A–D***	**Free?**	**Description**
LCA in Sustainable Architecture (LISA)	Yes	A, B, C, D	Yes	LISA is an Australian tool that was developed "in response to requests by architects and industry professionals for a simplified LCA tool to assist in green design".
LEGEP (*Lebenszyklus-Gebäude-Planung*: A German abbreviation for life cycle-building-design)	No	A, B, C	No	LEGEP is a tool for integrated life cycle analysis. It supports the planning teams in the design and construction of new and existing buildings or building products.
LCB Method	Yes	A, B, C, D	Yes	LCB Method is a "simplified" methodology for estimating GHG emissions resulting from a building's construction. It is a calculating spreadsheet that builds emission data for the construction phase, reuse/deconstruction phase and renovation.
Sustainable Minds	Yes	A, B, C, D	No	Sustainable Minds is designed as a product and process LCA tool. It has a limited amount of data that can be used for buildings; mostly this would be on a materials level.
The Environmental Assessment and Management (TEAM)	No	A, B, C	Yes	TEAM is a professional tool for evaluating the life cycle environmental and cost profiles of products and technologies.

Note: *A: Production/manufacturing and construction stages (cradle to gate); B: Use stage; C: End of life stage; D: Reuse, recovery and recycling stage.
Source: Lehtinen et al. (2011) and Simonen et al. (2012)

LCB Method is chosen among these tools. LCB Method is free, simple, relatively accurate (Fabre, 2009) and supports full LCA (Wang, Wu and Zhang, 2016). This tool is built and promoted for architects, engineers, construction managers, owners, or anyone interested in low carbon buildings across the design and construction industry. It is built to handle all building types, as well as, residential, commercial, industrial, interior design and infrastructure project types (Simonen et al., 2012).

THE CONCEPT OF LOW-CARBON BUIDLINGS

Low carbon content building is one of the techniques of sustainable development in which attempt is made for reducing emissions by using low carbon emission materials and low carbon emission techniques (Landage, 2013). A building emits GHG during its whole lifetime, therefore engineering a low-carbon building is a progress that concerns all stages of the building life.

Low-Carbon Building Classification

The LCB Method 2009 proposes LCB classification as illustrated in Figure 1.

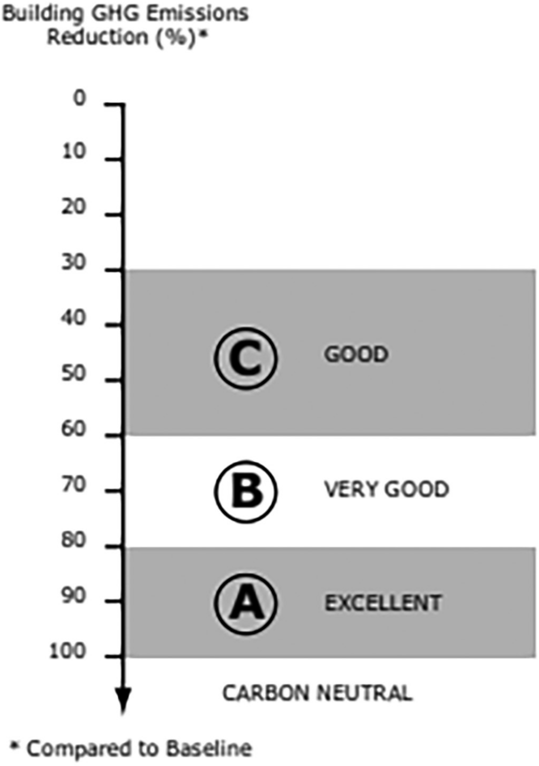

Figure 1. Low-Carbon Buildings Proposed Classification

Source: Fabre (2009)

Key Definitions

1. Baseline building: the building which would most likely has been constructed if no particular GHG emissions reduction strategies had been considered (Fabre, 2009).
2. Project building: the building which is designed by project team with GHG emissions reduction strategies (Fabre, 2009).

LOW-CARBON BUILDINGS: A STEP BY STEP APPROACH

LCB Method (First Edition, 2009)

The LCB Method recommends the step by step approach (see Figure 2) for achieving the desired emissions reduction performance.

The project team should focus on phases 1 to 3 of the process as a priority (Fabre, 2009). Since estimation for the case study is based on the third edition of LCB Method, here only the most significant factors of the first edition are introduced.

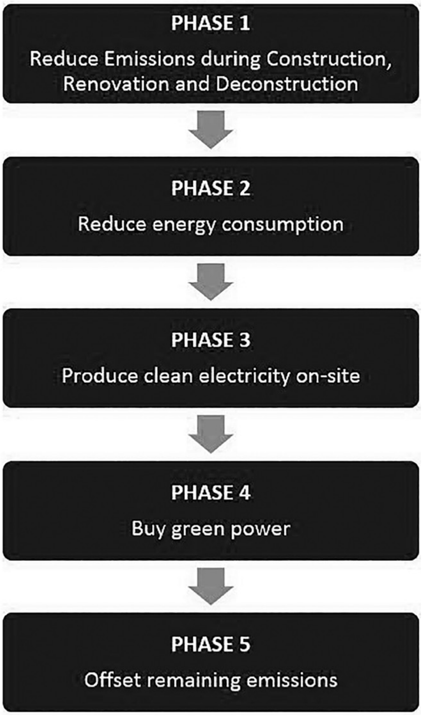

Figure 2. LCB Method: A Step by Step Approach (First Edition)

Source: Fabre (2009)

Phase 2 from the first edition: Reduce energy consumption

After construction, a building has an "operational life" of approximately 50 years. GHG are emitted as a consequence of the energy used by the building for lighting, artificial heating and cooling, etc. Most of the time, this energy is generated by the burning of fossil fuels such as coal, oil, gas, etc. (Fabre, 2009). There are consequently three ways to reduce the emissions of a building during operation:

1. To install energy-efficient systems.
2. To produce on-site or purchase renewable energy, in particular clean electricity.
3. To use passive solar building strategies in order to reduce energy consumption.

Moreover, it should be mentioned that medium to heavyweight construction is likely to provide more potential for achieving higher levels of indoor comfort and reduced lifecycle CO_2 emissions (Hacker et al., 2008).

Phase 3 from the first edition: Produce clean electricity on-site

Renewable energy sources (such as wind, sunlight, biomass.) can provide part of the energy, to in theory all the energy of a building. If embodied emissions are excluded, the electricity produced from renewable energy is considered to be emissions free, and the associated emission factor is:

EFrenewable = 0g CO_2 – e/kWh (Fabre, 2009).

LCB Method 3.0 (Third Edition, 2011)

The life cycle GHG emissions/removals of the project building shall be estimated by the step-by-step approach as shown in Figure 3.

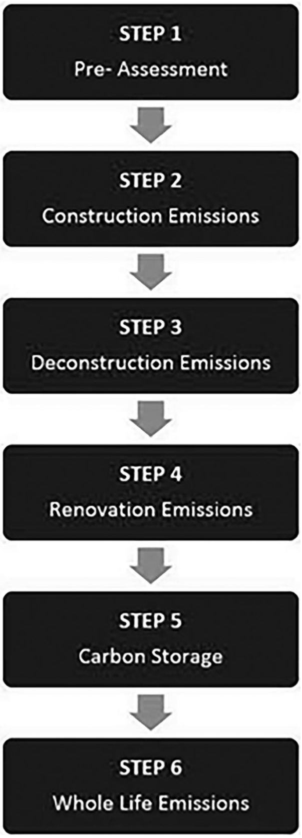

Figure 3. LCB Method: A Step by Step Approach (Third Edition)

Source: Fabre (2012)

Step 1: Pre-assessment

Estimate the contribution of each material to the life cycle emissions of the building prior to the detailed assessment by doing the pre-assessment. The pre-assessment is intended to identify the sources of emissions that shall be included in the assessment (Fabre, 2012). This step can be estimated by www.shapedearth.com.

Step 2: Construction emissions

The construction sector is the largest global consumer of materials (Giesekam et al., 2016) and over half the embodied carbon in construction is associated with the consumption of materials (Giesekam et al., 2014). Generally, GHG are emitted during five phases in construction (see Figure 4). Emissions associated with the building construction are calculated as shown in Equations 1, 2 and 3 (Fabre, 2012).

$$E_{CC} = {}_{\text{mat}, i} + E_{\text{trans mat}, i}) \qquad \text{Eq. 1}$$

$$E_{\text{mat}, i} = W_{\text{mat}, i} \times EF_{\text{mat}, i} \qquad \text{Eq. 2}$$

$$E_{\text{trans mat}, i} = W_{\text{mat}, i} \times d_{\text{trans mat}, i} \times EF_{\text{trans mat}, i} \qquad \text{Eq. 3}$$

Figure 4. Emissions of GHG during Construction Phase

Example for wall's material

Wall's material for the project building is considered to be light expanded clay aggregate (LECA) blocks and for a baseline building is clay brick.

LECA block for the project building:

$W_{\text{mat}} = 605{,}858$ kg, $EF_{\text{mat}} = 0.249$ kgCO$_2$e/kg, $d_{\text{trans mat}} = 50$ km, $EF_{\text{trans mat}} = 0.000125$ kgCO$_2$e/kg.km

Notes:

1. If the vehicle is empty on its return, multiply its emission factor by 1.8.
2. if the quantity of materials shown on the drawing is used, account for construction waste by multiply this quantity by 1.09.

$$E_{\text{mat}, i} = 605{,}858 \times 1.09 \times 0.249 \approx 164{,}435.9 \text{ kgCO}_2\text{e}$$

$$E_{\text{trans mat}, i} = 605{,}858 \times 1.09 \times 50 \times 0.000125 \times 1.8 \approx 7{,}429.3 \text{ kgCO}_2\text{e}$$

$$E_{CC} = 164{,}435.9 + 7429.3 = 171{,}865.2 \text{ kgCO}_2\text{e}$$

Clay brick for a baseline building:

$W_{mat} =$ 1,203,889 kg, $EF_{mat} =$ 0.48 $kgCO_2e/kg$, $d_{trans\ mat} =$ 20 km, $EF_{trans\ mat}$ = 0.000125 $kgCO_2e/kg.km$

$$E_{mat, i} = 1{,}203{,}889 \times 1.09 \times 0.48 \approx 629874.7 \text{ kgCO}_2\text{e}$$

$$E_{trans\ mat, i} = 1{,}203{,}889 \times 1.09 \times 20 \times 0.000125 \times 1.8 \approx 5{,}905 \text{ kgCO}_2\text{e}$$

$$E_{CC} = 629{,}874.7 + 5{,}905 = 635{,}779.7 \text{ kgCO}_2\text{e}$$

Results show that construction emissions for walls from LECA blocks is about 73% lesser than clay bricks.

Step 3: Deconstruction emissions

During deconstruction, materials constituting the building become waste. There are three main waste treatment methods: (1) disposal in landfills, (2) incineration and (3) recycling (Fabre, 2009). GHG are emitted during three phases in deconstruction (see Figure 5). Emissions associated with the building deconstruction are calculated as shown in Equations 4, 5 and 6.

$$E_{DC} = {}_{waste, i} + E_{trans\ waste, i}) \qquad \text{Eq. 4}$$

$$E_{waste, i} = W_{mat, i} \times (\delta_{land, i} \times EF_{land, i} + \delta_{inc, i} \times EF_{inc, i}) \qquad \text{Eq. 5}$$

$$E_{trans\ waste, i} = W_{mat, i} \times (\delta_{land, i} + \delta_{inc, i}) \times d_{trans\ waste} \times EF_{trans\ waste} \qquad \text{Eq. 6}$$

Step 4: Renovation emissions

The use phase of the building spans from the end of its construction to its deconstruction. The emissions anticipated to occur during this phase are the emissions associated with the replacement of the materials constituting the building (Fabre, 2012). GHG are emitted during several phases in building renovation (see Figure 6). Emissions associated with the building renovation are calculated as shown in Equations 7 and 8 (Fabre, 2012).

$$E_{RC} = {}_{mat, i} + E_{trans\ mat, i} + E_{waste, i} + E_{trans\ waste, i}] \times N_i) \qquad \text{Eq. 7}$$

$$\text{if } L_i < L,\ N_i = |\,L/L_i\,|\text{, if } L_i \geq L,\ N_i = 0 \qquad \text{Eq. 8}$$

Figure 6. Emissions of GHG during Renovation Phase

Step 5: Carbon storage

Carbon storage may arise when materials containing biogenic carbon (e.g., wood) or materials having the ability to take up atmospheric carbon over their life cycle (e.g., cement) are used on the project (Fabre, 2012). Equation 9 illustrates how to calculated carbon storage (Fabre, 2012).

$$R_{CS} = (-1) \times {}_{\text{mat}, i} \times [\delta_{\text{conc}, i} \times K_{\text{conc}} + \delta_{\text{wood}, i} \times K_{\text{wood}}] \times [1 - \delta_{\text{rec}, i}] \times [N_i + 1]) \qquad \text{Eq. 9}$$

Step 6: Whole life emissions

Total emissions of the building are calculated as illustrated in Equation 10 (Fabre, 2012).

$$E_{WLC} = E_{CC} + E_{DC} + E_{RC} + R_{CS} \qquad \text{Eq. 10}$$

Emissions from site activities (site work) and site land use change for construction, deconstruction and renovation should be estimated as below. Estimation of the emissions from construction site work and land use change as shown in Table 2 and Table 3.

Table 2. Default Emission Factors for Construction Site Work

Type of Project	**Emission Factor kgCO$_2$e/m^2 GFA**
Residential	20
Non-residential	12

Source: Fabre (2012)
Note: GFA = Gross Floor Area

Table 3. Default Emission Factors for Site Land Use Change

Land Use Change	**Emission Factor kgCO$_2$e/m^2**
Forestland <-> Hardscape	±30
Forestland <-> Grassland	±26
Grassland <-> Hardscape	±4

Note: Land use change may occur on-site as a consequence of the construction activities. Multiply the surface area of the disturbed land by the appropriate emission factor from the table (+ve if loss of biomass; –ve if gain of biomass).
Source: Fabre (2012)

The emissions from deconstruction site work are estimated as indicated in Equation 11 while for the emissions from renovation site work, the estimation is as indicated in Equation 12 (Fabre, 2012).

$$\text{GHG emissions} = E_{\text{site work}}/2.5 \qquad \text{Eq. 11}$$

$$\text{GHG emissions} = E_{\text{site work}} \times L/75 \qquad \text{Eq. 12}$$

CASE STUDY

Air pollution and its consequences (such as economic pollution) have caused irreparable damage especially in industrial cities of Iran, like Tehran (Karimzadegan et al., 2008). energy consumption per capita in domestic and commercial sector is 1.9 times more than the global average also using renewable energy sources are lesser than global average (*Iran's Energy Balance 2012* [2013]). Therefore, it seems a method which can focus on both energy and GHG emissions issues are vital.

Project site is located in Jashnvareh Blvd, sixth zone of district four, Tehran. District four has the second highest number of industrial services unites in Tehran city. This could help to reduce materials transport emissions. The site is located near to taxi station, bus stop and subway station which provides easy access to the site.

Estimating Building Lifetime GHG Emissions by LCB Method Version 3.0

Step 1: Pre-assessment

On this stage, emissions are estimated in www.shapedearth.com (Fabre, 2011) and some data like emission factors are available from www.lcbmethod.com/appendix (Fabre, 2014).

The construction industry requires the extraction of vast quantities of materials and this, in turn, results in the consumption of energy resources and the release of deleterious pollutant emissions to the biosphere (Hammond and Jones, 2008). To minimise emissions, it is essential to device technologies to produce building materials and products with minimum amount of energy expenditure (Reddy, 2009). Therefore, selecting materials with lower embodied carbon such as stabilised mud blocks, compacted fly ash blocks, rammed earth walls and blended cements can be used in low-carbon projects. This study is tried to use technology and materials which are common and available for construction in Iran in order to verify that low-carbon buildings could be built by common materials and technologies. Table 4 shows materials consist in the project building.

Total emissions for the project building are estimated about 55,567 kgCO_2e. Table 5 shows materials consist in a baseline building with a total emission for a baseline building is estimated about 89,568 kgCO_2e. On the other notes, Tables 6 to 10 are required in the next steps (Step 2 to 5) for more accurate estimations and actual distances mostly used for this project.

Table 4. The Project Building Materials and Materials Data

Material	***EF*mat, *i* kgCo_2e/kg**	**Material Weight (kg)**	**Material density (kg/m^3)**	**Vol. (M^3)**	**Material Service Life (Year)**	**Transport to Site (km)**	**Vehicle**
Aluminium gutter	9.18	8,910	2,700	3.3	Varied	15	Heavy truck
Aluminium	1.81	2,214	2,700	0.82	Varied	15	Heavy truck
Aluminium sheet	9.18	81,000	2,700	30	Varied	15	Heavy truck
Carpet	5.86	490	490	1	20	15	Light truck
Ceramic tile	0.5	3,591	2,100	1.71	50	13	Light truck
Concrete (fly ash)	0.004	2,776,970	1,750	1586.84	Varied	4	Heavy truck
Light weight concrete	0.091	85,800	600	143	Varied	4	Heavy truck
Concrete (sand, cement, screed)	0.93	279,573	2,100	133.13	Varied	4	Heavy truck
Concrete (rebar)	1.4	2,054,875	2,500	821.85	Varied	4	Heavy truck
Damp proofing	4.5	1,809	900	2.01	Life	2	Light truck
Door frame	35	3,726	2,700	1.38	30	15	Heavy truck
Door fibreglass panel	35	11,304	1,800	6.28	30	15	Heavy truck
Glass	0.74	102,090	3,000	34.03	35	19	Heavy truck
Gypsum plaster	0.13	347,867	1,300	267.590	50	2	Light truck
Moisture barrier-bituminous	0.5	36,927	900	41.03	15	2	Light truck
Thermal barrier- fibreglass	1.43	5,645.76	32	176.43	60	3.5	Light truck
Acoustic barrier- fibreglass	1.43	1,848.96	32	57.78	60	3.5	Light truck
Lean concrete	0.132	612,240	2,400	255.1	Varied	4	Heavy truck
LECA block	0.249	605,858	1,100	550.78	Life	50	Heavy truck
Metal-steel	0.47	290,842.5	7,850	37.05	Varied	15	Heavy truck
Mortar (sand, cement)	0.16	432,558	2,100	205.98	Varied	4	Heavy truck
Paint	3.052	2,449	–	28.12	15	2	Light truck

(continued on next page)

Table 4. (*continued*)

Material	***EF*mat, *i*** **$kgCo_2e/kg$**	**Material Weight (kg)**	**Material density (kg/m^3)**	**Vol. (M^3)**	**Material Service Life (Year)**	**Transport to Site (km)**	**Vehicle**
Aggregates (sand, gravels, crushed stones)	0.004	3,254,148	2,700	1205.24	Life	100	Heavy truck
Sand	0.0083	87,536	1,600	54.71	Life	0	Human
Soil	0.004	139,230	1,700	81.9	Life	100	Heavy truck
Stabilised rammed earth	0.058	314,780	2,000	157.39	Life	0	Human
Stainless steel	0.47	40,192	7,850	5.12	Varied	15	Heavy truck
Stone (floor finish)	0.15	142,625	2,500	57.05	50	13	Light truck

Table 5. A Baseline Building Materials and Materials Data

Material	***EF*mat, *i*** **$kgCo_2e/kg$**	**Material Weight (kg)**	**Material Density (kg/m^3)**	**Vol. (M^3)**	**Material Service Life (Year)**	**Transport to Site (km)**	**Vehicle**
Aluminium gutter	9.18	8,910	2,700	3.3	Varied	15	Heavy truck
Aluminium	1.81	2,214	2,700	0.82	Varied	15	Heavy truck
Aluminium sheet	9.18	81,000	2,700	30	Varied	15	Heavy truck
Carpet	5.86	490	490	1	20	15	Light truck
Ceramic tile	0.5	3,591	2,100	1.71	50	13	Light truck
Light weight concrete	0.091	85,800	600	143	Varied	4	Heavy truck
Concrete (sand, cement, screed)	0.93	279,573	2,100	133.13	Varied	4	Heavy truck
Concrete (rebar)	1.4	3,902,725	2,500	1,561.09	Varied	4	Heavy truck
Damp proofing	4.5	1,809	900	2.01	Life	2	Light truck
Door frame	35	3,726	2,700	1.38	30	15	Heavy truck

(*continued on next page*)

Table 5. *(continued)*

Material	*EF*mat, *i* $kgCo_2e/kg$	Material Weight (kg)	Material Density (kg/m^3)	Vol. (M^3)	Material Service Life (Year)	Transport to Site (km)	Vehicle
Door fibreglass panel	35	11,304	1,800	6.28	30	15	Heavy truck
Glass	0.74	102,090	3,000	34.03	35	19	Heavy truck
Glue	6	1,265	1,100	1.15	15	2	Light truck
Gypsum plaster	0.13	347,867	1,300	267.590	50	2	Light truck
Moisture barrier- bituminous	0.5	36,927	900	41.03	15	2	Light truck
Polystyrene	3.29	10,539	45	234.21	60	3.5	Light truck
Lean concrete	0.132	612,240	2,400	255.1	Varied	4	Heavy truck
Mortar (sand, cement)	0.16	432,558	2,100	205.98	Varied	4	Heavy truck
Paint	3.052	2,449	–	28.12	15	2	Light truck
Aggregates (sand, gravels, crushed stones)	0.004	3,254,148	2,700	1,205.24	Life	100	Heavy truck
Sand	0.0083	87,536	1,600	54.71	Life	0	Human
Stainless steel	0.47	40,192	7,850	5.12	Varied	15	Heavy truck
Stone (floor finish)	0.15	142,625	2,500	57.05	50	13	Light truck
Clay brick	0.48	1,203,889	1,700	708.17	50	20	Heavy truck
Asphalt shingle	0.176	301,400	2,200	136.78	20	5	Heavy truck
Mineral fibre tile	2.9	189,600	800	236.79	25	10	Heavy truck

Table 6. Default Emission Factor of the Vehicle Used for Materials Transportation

Vehicle	**EF_{trans} mat (gCO_2e/ton.km)**
Human and animal transportation	0
Truck-light-duty truck (up to 3.5 tons gross weight)	590
Truck-medium- and heavy-duty truck (3.5 tons gross weight or more)	125
Rail	30
Barge	30
Boat-bulk carrier	5
Boat-containers	15
Airplane	1,350

Source: Fabre (2012)

Table 7. Default Proportion (wt %) of Each Materials Sent to Landfill (Δ land), Incinerator (Δ inc) and Recycling (Δ rec)

Material	**δ_{land} (%)**	**δ_{inc} (%)**	**δ_{rec} (%)**
Concrete	45	0	55
Other mineral materials (non-metallic)	45	0	55
Wood	40	35	25
Metal	25	0	75
Plastics	70	20	10
Others, mixed	100	0	0

Source: Fabre (2012)

Table 8. Default Transportation Emissions of Each Material from Gate (Factory) to Site

Material	**$d_{trans\ mat}$ (km)**
Concrete	10
Other mineral materials (non-metallic)	100
Wood	350
Metal	500
Plastics	1,050
Others, mixed	1,500

Source: Fabre (2012)

Table 9. Default Emission Factor of Materials in Landfill and in Incinerator

Material	EF_{land} (kgCO$_2$e/ton)	EF_{inc} (kgCO$_2$e/ton)
Concrete	0	0
Other mineral materials (non-metallic)	0	0
Wood	2,150	1,560
Metal	0	0
Plastics	0	2,800

Source: Fabre (2012)

Table 10. Default Transportation Distance of Materials Sent to Landfill, Incinerator and Recycling Plant

Destination	Distance (km)
Landfill	100
Incineration Plant	100
Recycling Plant	100

Source: Fabre (2009)

Step 2: Construction emission

Construction emissions for the baseline and the project buildings are calculated as shown in Table 11.

Table 11. Construction Emissions for the Baseline and the Project Buildings

Project Building		Baseline Building	
Material	**Result (kgCO$_2$e)**	**Material**	**Result (kgCO$_2$e)**
Aluminium gutter	89,187.9	Aluminium gutter	89,187.9
Aluminium	4,370.7	Aluminium	4,370.7
Aluminium sheet	810,800.1	Aluminium sheet	810,800.1
Carpet	3,138.3	Asphalt shingle	58,190
Ceramic tile	2,011	Carpet	3,138.3
Concrete (fly ash)	14,831.7	Ceramic tile	2,011
Light weight concrete	8,594.6	Clay brick	635,779.7
Concrete (sand, cement, screed)	283,677.3	Light weight concrete	8,594.6
Concrete (rebar)	3,137,755	Concrete (sand, cement, screed)	283,677.3
Damp proofing	8,877.3	Concrete (rebar)	5,959,386.8
Door frame	142,159.9	Damp proofing	8,877.3

(continued on next page)

Project Building		Baseline Building	
Material	**Result ($kgCO_2e$)**	**Material**	**Result ($kgCO_2e$)**
Door fibreglass panel	431,289.1	Door frame	142,159.9
Glass	8,2821.4	Door fiberglass panel	431,289.1
Gypsum plaster	50,098	Glass	82,821.4
Moisture barrier (bituminous)	20,210.7	Glue	8,276
Thermal barrier (fibreglass)	8,826.2	Gypsum plaster	50,098
Acoustic barrier (fibreglass)	2,890.5	Moisture barrier (bituminous)	20,210.7
Lean concrete	88,689.6	Lean concrete	88,689.6
LECA block	171,865.2	Mortar (sand, cement)	75,862.4
Metal-steel	150,068.5	Mineral fibre tile	599,790.5
Mortar (sand, cement)	75,862.4	Paint	8,152.6
Paint	8,152.6	polystyrene	37,842.7
Rubble	86,901.9	Rubble	86,901.9
Sand	791.9	Sand	791.9
Soil	4,021.6	Stainless steel	20,738.1
Stabilised rammed earth	19,900.4	Stone (floor)	25,620.8
Stainless steel	20,738.1		
Stone (floor)	25,620.8		
Construction site work*	62,700	Construction site work*	62,700
site land use change	6,378.8	Site land use change	20,955.6
Total construction emission	5,823,231.5 $kgCO_2e$	Total construction emission	9,626,914.9 $kgCO_2e$

Notes: *Area (GFA) = 5,225 m^2

1. If the vehicle is empty on its return, multiply its emission factor by 1.8.
2. If the quantity of materials shown on the drawing is used, account for construction waste by multiply this quantity by 1.09.

Step 3: Deconstruction emissions

Deconstruction emissions for the baseline and the project buildings are calculated as shown in Table 12.

Table 12. Deconstruction Emissions for the Baseline and the Project Building

Project Building		**Baseline Building**	
Material	**Result (kgCO_2e)**	**Material**	**Result (kgCO_2e)**
Bituminous	22,721.1	Bituminous	22,721.1
Damp proofing	1,112	Damp proofing	1,112
Fibreglass	11,563.8	Expanded polystyrene (EPS)	6,483.3
		Fibreglass	6,954.6
		Glue	779
Deconstruction site work	25,080	Deconstruction site work	25,080
Total deconstruction emission	60,476.9 kgCO_2e	Total deconstruction emission	63,130 kgCO_2e

Note: If the vehicle is empty on its return, multiply its emission factor by 1.8.

Step 4: Renovation emissions

Renovation emissions for the baseline and the project buildings are calculated as shown in Table 13.

Table 13. Renovation Emissions for the Baseline and the Project Building

Project Building		**Baseline Building**	
Material	**Result (kgCO_2e)**	**Material**	**Result (kgCO_2e)**
Carpet	3,138.3	Carpet	3,138.3
Door frame	142,159.9	Door frame	142,159.9
Door panel	438,243.7	Door panel	438,243.7
Moisture barrier bituminous	128,795.4	Moisture barrier bituminous	128,795.4
Paint	24,457.5	Paint	24,457.8
		Glue	27,165
		Asphalt shingle	116,380
		Mineral fibre tile	599,790.5
Renovation site work	41,382	Renovation site work	41,382
Total renovation emission	778,176.8 kgCO_2e	Total renovation emission	1,521,512.6 kgCO_2e

Step 5: Carbon storage

Carbon storage for the baseline and the project buildings are calculated as shown in Table 14.

Table 14. Carbon Storage for the Baseline and the Project Building

Project Building		**Project Building**	
Material	**Result ($kgCO_2e$)**	**Material**	**Result ($kgCO_2e$)**
Concrete (fly ash)	–9,534.7	Light weight concrete	–324
Light weight concrete	–324	Concrete (sand, cement, screed)	–1,371.2
Concrete (sand, cement, screed)	–1,371.2	Mortar (sand, cement)	–2,121.6
Mortar (sand, cement)	–2,121.6	Concrete (rebar)	–19,142.8
Concrete (rebar)	–10,079.1	Lean concrete	–30,029.6
Lean concrete	–30,029.6		
LECA block	–2,080.2		
Total carbon storage	–55,540.4 $kgCO_2e$	Total carbon storage	–52,989.2 $kgCO_2e$

Step 6: Whole life emissions

Whole life emissions for the project building: 6606344.8 $kgCO_2e$
Whole life emissions for a baseline building: 11158568.3 $kgCO_2e$

Comparison between pre-assessment and detailed assessment are shown in Table 15.

Table 15. Comparison between Pre-Assessment (Step 1) and Detailed Assessments (Step 2 To 5)

	Project Building Emissions ($kgCO_2e$)	**Baseline Building Emissions ($kgCO_2e$)**	**Emission Reduction Performance**	**LCB Classification**
Pre-assessment results	55,567	89,568	38%	Class C (good)
Detailed assessments results	6,606,344.8	11,158,568.3	40.8%	Class C (good)

Some actions which are used in the project building to reduce emissions are: using recyclable materials, minimise site land use change, use earth material of the site (rammed earth), using durable materials and reducing transport distance by using local materials.

CONCLUSION

Overall, the amount of emissions from pre-assessment step for the project building is 38% lesser than a baseline building. Results of the detailed assessment (step 2 to 5) justify the pre-assessment estimation, and illustrate that the project building emission is 40.8% lesser than baseline building. Therefore, according to low-carbon buildings classifications, the project building can be ranked in Class C (good).

Estimations indicate that the construction phase has the highest amount of emissions compared to other phases. As can be seen by estimations, some of the effective factors to reduce emissions are building structure and materials transportation. Some effective ways to reduce emissions from buildings are:

1. Choose recycled materials for the structure: fly ash concrete, recycled, steel, wood from well-managed forest.
2. Reduce materials/products quantities.
3. Substitute materials with the ones which have lower emission factors.
4. Reduce development area.
5. Use materials that will be recycled.
6. Reuse materials such as materials salvaged from other project.
7. Use durable materials.
8. Use low embodied carbon material such as rammed earth, straw and etc.
9. Use local materials to reduce transport emissions.
10. Reduce development area and preserve biodiversity.
11. Produce clean electricity on-site.
12. Use passive design and technologies.

It should be mentioned that some programmes like Renewable Energy Certificated (RECs) and carbon offset credits are needed to create carbon neutral buildings. Unfortunately, these programs are not available in Iran. However, using carbon reduction opportunities, as mentioned above, can be helpful to minimise emissions from building industry as much as possible.

APPENDIX

This is a list of the abbreviated terms used throughout the article and the definitions:

$d_{\text{trans mat}, i}$	Distance gate-site for material *i*
$d_{\text{trans waste}}$	Distance site-disposal
E_{cc}	Construction emissions (construction carbon)
E_{dc}	Deconstruction emissions (deconstruction carbon)
E_{rc}	Renovation emissions (renovation carbon)
$E_{\text{mat}, i}$	Cradle-to-gate emissions of material *i*
$E_{\text{trans mat}, i}$	Transport emissions of material *i* from gate to site
$E_{\text{trans waste}, i}$	Transport emissions of material *i* from site to grave
$E_{\text{waste}, i}$	Waste treatment emissions of material *i*
$EF_{\text{inc}, i}$	Emission factor of material *i* in incinerator
$EF_{\text{land}, i}$	Emission factor of material *i* in landfill
$EF_{\text{mat}, i}$	Cradle-to-gate emission factor of material *i*
$EF_{\text{trans mat}, i}$	Emission factor of the vehicle used to transport material *i* to site
$EF_{\text{trans waste}}$	Emission factor of the vehicle used to transport waste to disposal
$K_{\text{conc}} = 0.01$; $K_{\text{wood}} = 1.56$	K_{conc} is the atmospheric carbon, expressed in kgCO$_2$e, taken up by 1 kg concrete over a 100-year period. K_{wood} is the carbon content, expressed in kgCO$_2$e, of 1 kg wood (wet weight).
L	Expected service life of the building
L_i	Expected service life of material *i*
n	Total number of materials included in the assessment
N_i	Expected number of replacement instances of material *i*
$W_{\text{mat}, i}$	Weight of material *i*
$\delta_{\text{conc}, i}$	Proportion (wt %) of concrete in material *i*
$\delta_{\text{inc}, i}$	Proportion (wt %) of material *i* sent to incinerator
$\delta_{\text{land}, i}$	Proportion (wt %) of material *i* sent to landfill
$\delta_{\text{rec}, i}$	Proportion (wt %) of material *i* sent to recycling
$\delta_{\text{wood}, i}$	Proportion (wt %) of eligible wood in material *i*

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